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Recent Developments in the TRANSIMS Approach to Emission Estimation

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RECENT DEVELOPMENTS IN THE TRANSIMS APPROACH TO EMISSION ESTIMATION

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ABSTRACT

Transportation systems play a significant role in urban air quality, energy consumption and carbon-dioxide emissions. Recently, it has been found that current systems for estimating emissions of pollutants from transportation devices lead to significant inaccuracies. Most of the existing emission modules use very aggregate representations of traveler behavior and attempt to estimate emissions on typical driving cycles. However, recent data suggests that typical driving cycles produce relatively low emissions with most emissions coming from off-cycle driving, cold-starts, malfunctioning vehicles, and evaporative emissions.

TRANSIMS is a simulation system for the analysis of transportation options in metropolitan areas. Its major functional components are: (1) a population disaggregation module, (2) a travel planning module, (3) a regional microsimulation module, and (4) an environmental module. The purpose of the environmental module is to translate traveler behavior into consequent air quality. The environmental module uses information from the TRANSIMS planner and the microsimulation. The TRANSIMS system holds the promise of a more complete description of the role of heterogeneity in transportation in emission estimation.

The TRANSIMS micro-simulation produces second by second vehicle positions defined by 7.5 meter cell locations. Previous work focused on the adequacy of 30 meter position aggregations

coupled to 7.5 meter-per-second, speed bins as input into the module that produces the speed and power distributions for use by the emission module. The most recent work extends the approach to freeway on-ramps and to the end of the links where decelerations dominate. In addition, the performance of aggregations from actual microsimulation output are used instead of aggregate data drawn from measured continuous data. The model is calibrated with the use of measured speeds and accelerations for a uncongested freeway, a moderately congested freeway, a fast arterial and one of the on-ramps examined. Calibration constants are chosen to give the appropriate specific power for vehicles undergoing hard-deceleration, intermediate acceleration, and hard-acceleration.

The speeds and accelerations are used with a new modal emissions model developed by University of California at Riverside and University of Michigan investigators. The new modal emissions model was developed after extensive testing of over 300 light-duty vehicles chosen to represent the major emission classes currently on the highways. The validation cases include several freeway on-ramps, two levels of congestion on arterials, and three levels of congestion on freeways.

The approach to estimation of emissions from vehicles that have not achieved steady-state engine and catalyst temperatures is also described.

OVERVIEW

Emissions from transportation sources play a major role in urban air quality. However the transportation modeling community and the air quality modeling community have developed their models separately and have made adjustments to each suite of models to produce a fit with the others's model requirements. In addition both sets of models have been hampered by deficiencies in the quality and quantity of relevant data. The result is that some important questions cannot be properly addressed with the current sets of tools. For example, on the transportation side the models have trouble dealing with peak-spreading, and induced demand. On the air quality side the models are not designed to estimate the effects of "green wave" signalization. Green wave signalization permits vehicles traveling at or near the speed limit to be in phase with the green lights. The TRansportation ANalysis and SIMulation System (TRANSIMS) is being developed to address this problem as well as many other transportation analysis challenges. TRANSIMS is one part of the multi-track Travel Model Improvement Program sponsored by the U. S. Department of Transportation, the Environmental Protection Agency, and Department of Energy. Los Alamos National Laboratory is leading this major effort to develop new, integrated transportation and air quality forecasting procedures necessary to satisfy the Transportation Equity Act of the 21st century and the Clean Air Act and its amendments.

TRANSIMS is a set of integrated analytical and simulation models and supporting data bases. The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. TRANSIMS predicts trips for individual households, residents and vehicles rather than for zonal aggregations of households. TRANSIMS also predicts the movement of individual freight loads. A regional microsimulation executes the generated trips on the transportation network, modeling the individual vehicle interactions and predicting the transportation system performance.

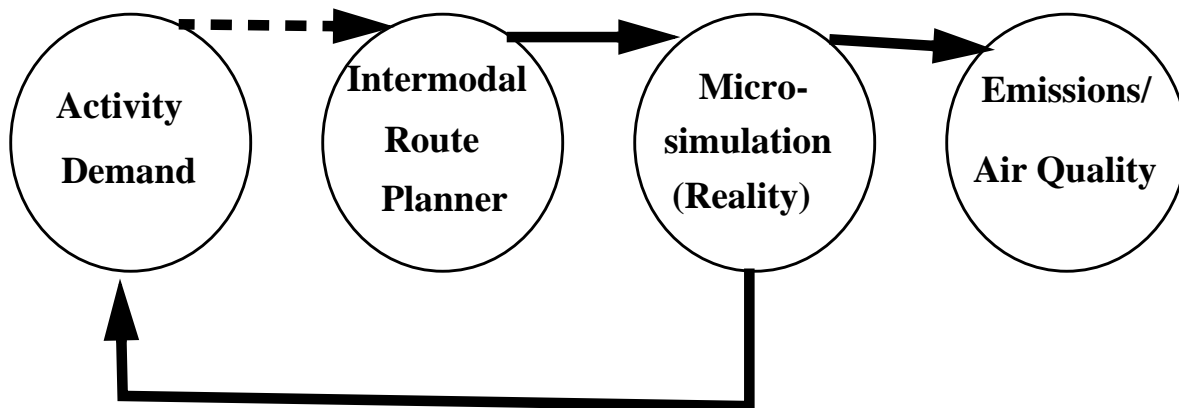
The emission module of TRANSIMS uses the Comprehensive Modal Emission Model (CMEM) developed under National Cooperative Highway Research Program (NCHRP) Project 25-11^{1,2}. The version of CMEM currently used in TRANSIMS has been developed for 23 different vehicle/technology classes of light duty vehicles. Extensive tests were carried out on over 300 vehicles chosen to represent the major types of emitters in the existing light-duty vehicle fleet. CMEM also incorporates other data to help draw associations between the tested vehicles and the fleet at large.

The choice of components in the TRANSIMS approach is driven by the goal of representing those details that may influence the answer of the question being asked. In the context of travel the focus is on the individual traveler. Models³ will be used to translate emissions into concentrations of pollutants.

METHODOLOGY

TRANSIMS integrates advances in system science, algorithms, simulations, display techniques, databases, computer tools, and computer technology. It proceeds through several steps to create a virtual metropolitan region with a comprehensive representation of the region's individuals, their activities, and their interactions with each other and with the transportation infrastructure. A high level depiction of these steps is shown in Figure 1.

Figure1. Major Modules in the TRANSIMS Framework.



Development of synthetic travelers

Using census data, TRANSIMS generates a synthetic population of households and individuals with the same demographic distribution as the region's actual population and locates the households and businesses along the region's streets⁴. With data about people's activities and the trips they make to carry out those activities, it then builds a model of household and individual activity demand that includes activity time and location.

Development of route plans

An Intermodal Route Planner uses information about the transportation system's link travel times and costs (including transit systems) to plan an individual's travel modes and routes for the day. These travel plans then are executed in a simulation of the movement of individuals across the transportation network, including their use of vehicles such as cars or buses, on a second-by-second basis. This virtual world of travelers mimics the traveling and driving behavior of real people in the region. The interactions of individual vehicles produce realistic traffic dynamics from which analysts can judge the overall performance of the transportation system and can estimate vehicle emissions.

Microsimulation of travel

The microsimulation executes the trip plans, following each traveler second-by-second through the network including transfers between travel modes. The microsimulation uses a cellular-automata approach in which each lane is broken into 7.5 meter cells, and vehicles are moved an integer number of cells in each second. Vehicles speed up, change lanes, or turn across on-coming lanes depending upon the gap available. They also randomly accelerate one-gap less than they otherwise would. The microsimulation provides an accurate description of major traffic features⁵, but it does not accurately describe the distribution of accelerations due to the quantum step nature of the CA approach. A major focus of this paper, as described in the section on emission modules, is the development and testing of techniques to produce appropriate speeds and accelerations from the microsimulation output.

System integration and feedback

The functionality of TRANSIMS however is more than just using activity demand to produce trip plans and then using trip plans to generate executed travel. A key element comes from the feedback of information from the executed travel in the microsimulation to the route planner and the activity demand and the executing the travel again. The interaction of information from the microsimulation back to the route planner can be used in two ways. First, iteration "relaxes" the model inherent to the simulation into a refined simulation solution of all travelers. In this way activities and trip plans for the synthetic travelers are adapted in response to encountered simulated travel difficulties or favorable experiences. Second, it models information movement from the subsystems to certain travelers according to specific ITS strategies.

The arrows in Figure 1 indicate the information flow. The solid arrows follow the iteration process in which modes, routes, and the activity departure times for the synthetic travelers are adjusted to improve travel performance.

The initial set of trip plans when executed by the microsimulation produces interactions among the travelers on the transportation network. The interactions may lead to unrealistic congestion delays on the freeways, arterials, local streets, transit queues, etc. An output subsystem accumulates link summary output from this simulated "real world." The accumulated information is generally average link travel times during fixed time intervals, say 15-minutes, but other traveler costs (e.g., transit fares, tolls, travel time variability) may be included as well. Using this information as an updated estimate of the network state, the intermodal route planner then finds possible new

modes, routes, and departure times for selected synthetic travelers⁶.

A subset of the travelers are chosen to find better travel times, lower financial costs, or lower travel-time variabilities when traveling to their destinations. The plans for all travelers, selected and not selected, are executed again in the microsimulation. Even though the travel plans have not changed for the unselected travelers, their interactions with selected travelers now differ and the executed travel for both sets of travelers changes. Continuing this iteration process, travel through the transportation system is adjusted until each individual executes, in some sense, his optimal trip for carrying out his activities given that all the other travelers are attempting to do the same. In this manner, modes, routes, and departure times are adjusted to avoid congested areas during peak periods.

This iteration process continues until the system relaxes to a stationary state. Note that stationary state for this system does not mean that everything remains the same between iterations. Rather relative invariability in selected output variables or measures of effectiveness determine when the system has relaxed to a “steady state.” Such measures also establish whether two states of the transportation system are close to one another or possibly equal.

Emission modules

Overview

The primary output of the transportation microsimulation module is summarized cellular-automata (CA) data. The CA describes the vehicle position in units of cells, velocity in units of cells per second, and the acceleration in units of cells per second per second. A typical cell size is 7.5 meters so that the resulting motion, in 16 mph increments, is too coarse to be used directly as input to the emissions module. We are developing an approach to produce realistic, smooth vehicle trajectories that can be used in the emissions module.

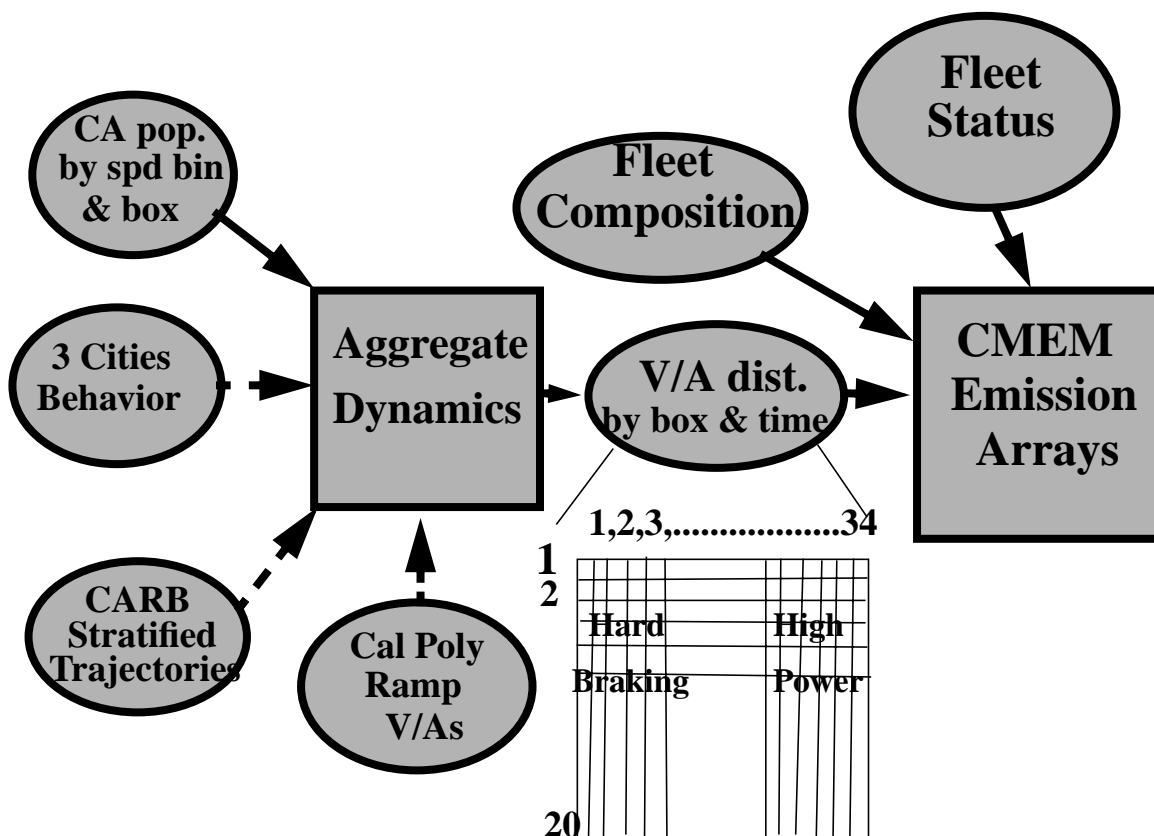
The emissions module treats heavy-duty vehicle, light-duty vehicle and evaporative emissions, but the focus of this paper is on light-duty tailpipe emissions. The overall approach for all three modules was described in a paper at last years annual meeting⁷. Figure 2 illustrates the information flow for the light-duty tailpipe module. The output of the microsimulation is aggregated into speed bins (in increments of 7.5 meters per second) and spatial segments (30 meters in length) and summed over an hour. The vehicles entering each link over each hour are grouped by soak-time (the length of time the engine was off prior to start of the current trip) and by integrated velocity-acceleration product. The velocity acceleration product is used as a surrogate for fuel consumption to give the stage of engine and catalyst warm-up. The simulation also provides the distribution of vehicle types that is used to construct the emission arrays.

The microsimulation output is used by the aggregated dynamics module to calculate the number of vehicles for each 4 mile per hour (mph) speed bin and each 20 mph squared per second power bin (more precisely, velocity (V) acceleration (A) product bin). The CMEM arrays, one which reflects emissions at constant power and one of which reflects differences in emissions associated with changes in power from one second to the next, are used to estimate the emissions for each speed and power bin. The contributions from each speed and power bin are summed to obtain the emissions. Three sets of empirical data have been used to estimate parameters in the aggregate dynamics model. First, during EPA’s three city studies⁸ many vehicles were fitted with a data-log-

ger that recorded times and speeds throughout the vehicle's travels for a significant period. The three cities data was used to estimate the distribution of high-power events (V A product greater than 50.) and hard-braking events (V A product less than -50.) by V A product. Second, the California Air Resources Board, supported the collection of vehicle trajectories on freeways and arterials with different levels of congestion⁹. A portion of the CARB trajectories were used for calibration constants and the distribution of V A product during hard-braking at the end of signalized links. Finally, investigators from California Polytechnic State University at San Luis Obispo collected distributions of velocities and accelerations on California freeway on-ramps¹⁰. A portion of the Cal Poly on-ramp data was used to estimate the distribution of V A product during high-power events occurring on on-ramps and to estimate empirical parameters. Separate portions of the CARB and Cal Poly data were used to validate the model.

Figure 2. Information flow in the light-duty vehicle, tailpipe emission module.

OVERVIEW OF LDV TAILPIPE MODULE



The light-duty tailpipe module treats tailpipe emissions from cars, light-duty trucks, and sport-utility vehicles. Important aspects include: (1) malfunctioning vehicles, (2) emissions from starts, (3) emissions with variable soak-times, (4) emissions from off-cycle conditions which render the pollution controls inefficient and (5) normal driving. With regard to off-cycle conditions, very high emissions occur at high power demands. The phrase off-cycle refers to conditions outside those that occur in the Federal Test Procedure¹¹. Emissions in this context are very sensitive to the precise acceleration that occurs at a specific speed. There are three major sets of information which must be developed: (1) what is the fleet composition, (2) what is the fleet status, and (3)

what is the fleet doing. Once these questions are answered the LDV tailpipe module can produce the emissions.

Composite-vehicle modal emissions

Fleet composition is developed from vehicle registration data, inspection and maintenance testing, or data developed for EPA's MOBILE model runs. Barth and his colleagues¹ have developed techniques to take registration data and produce vehicle populations in each of 23 categories required for their model. The categories include factors such as low or high engine to weight ratio, car or truck, mileage above or below 50,000, type of catalyst (2-way or 3-way), carbureted or fuel-injected, and high-emitting or normal emitting. In areas where there is a sophisticated inspection and maintenance program that tests vehicles on a dynamometer, improved estimates of the proportion of high-emitting vehicles can be made. With this approach, the role of inspection and maintenance is to transform some of the malfunctioning vehicles into normally operating vehicles.

At present, we are using the Comprehensive Modal Emission Model (CMEM), version 1.2, developed under National Cooperative Highway Research Program (NCHRP) Project 25-11^{1,2}. CMEM thus far has been developed for 23 different vehicle/technology classes of light duty vehicles. Extensive tests were carried out on over 300 vehicles chosen to represent the major types of emitters in the existing light-duty vehicle fleet. CMEM also incorporates other data to help draw associations between the tested vehicles and the fleet at large.

The model computes the tractive power by taking account engine friction losses, rolling resistance, wind resistance, changes in kinetic energy, and changes in potential energy. It also considers the power to drive accessories such as air conditioning and it estimates drivetrain efficiency. With the engine power known, it calculates the rate of fuel consumption and engine out emissions. It treats enrichment, enleanment, and stoichiometric operations as well as cold-start operation.

Once the engine-out emissions are calculated, catalyst pass fractions are used to calculate the tailpipe emissions. The approach uses a composite vehicle to represent vehicles in the same class. A regression approach was used to define the parameters required by the model. The vehicles were all tested over cycles involving very high power demands and a variety of driving patterns.

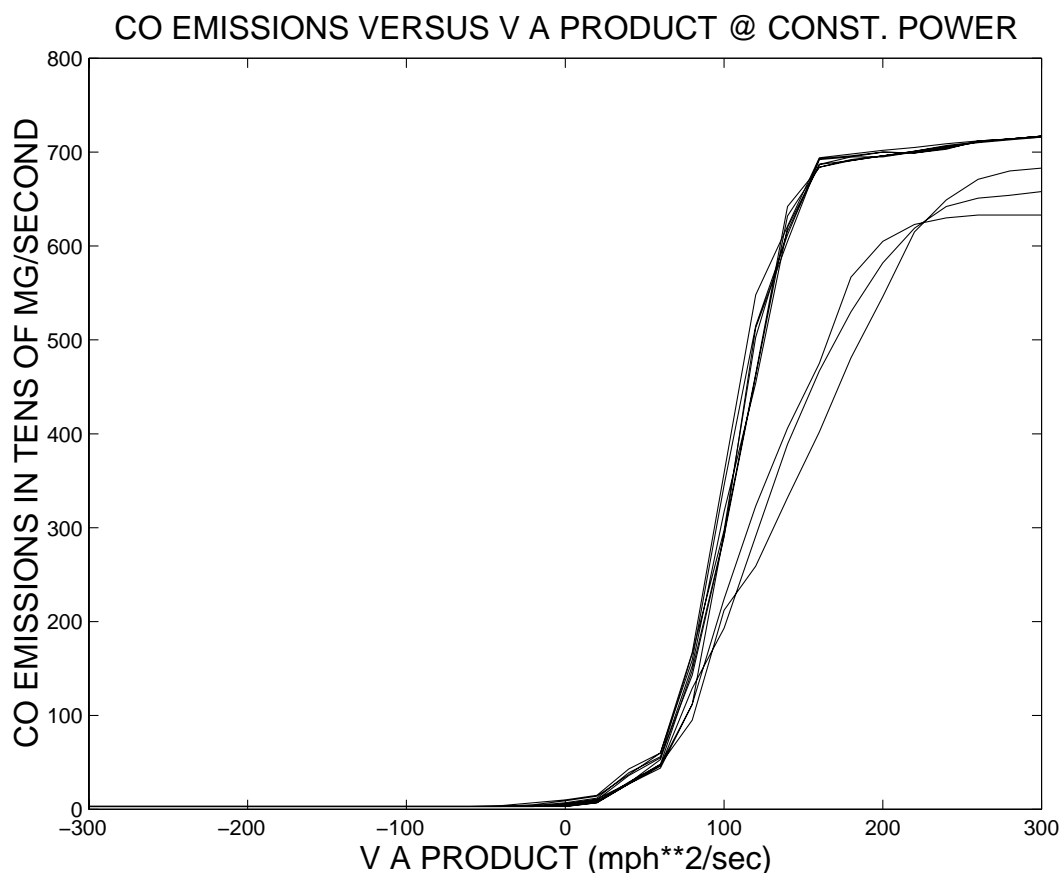
There are composite vehicles representing normal emitting cars categorized by technology, low and high power to weight ratios, and mileages above or below 50,000. The technology categories are: (1) no catalyst, (2) 2-way catalyst, (3) 3-way catalyst with carburetion, (4) 3-way catalyst with fuel injection, (5) Tier 1. Only the last two technologies are broken into mileage or power to weight ratio groupings. There are high emitting composite vehicles for technologies (3) through (5), but they are not further subdivided into power to weight ratios or mileage groupings.

There are composite vehicles representing normal-emitting trucks with model year categories: (1) pre-1979, (2) 1979 to 1983, (3) 1984 to 1987, (4) 1988 to 1993, (5) 1994 and newer. In age categories (1) through (3) there is only a single composite vehicle. For age category (4) there are categories for trucks above and trucks below 3750 pounds loaded vehicle weight, while for category (5) there is a category for trucks with loaded vehicle weights between 3751 and 5750 pounds and a category for gross vehicle weights between 6001 and 8500 pounds. There are composite vehicles representing high-emitting trucks for model years 1984 to 1987, 1988 to 1993, and 1994 and

newer. In the high-emitting category, there are no breakdowns by vehicle weight.

The choice of the particular form of the emission arrays; 4 mph speed bins and 20 mph squared per second power bins, is driven by the sensitivity of emissions to power and speed. Figure 3 displays the sensitivity of CO emissions to V A product for 10 speeds ranging from about 20 mph to about 60 mph. Incidentally, the Federal Test Procedure¹¹ limit is 96 mph squared per second in terms of V A product.

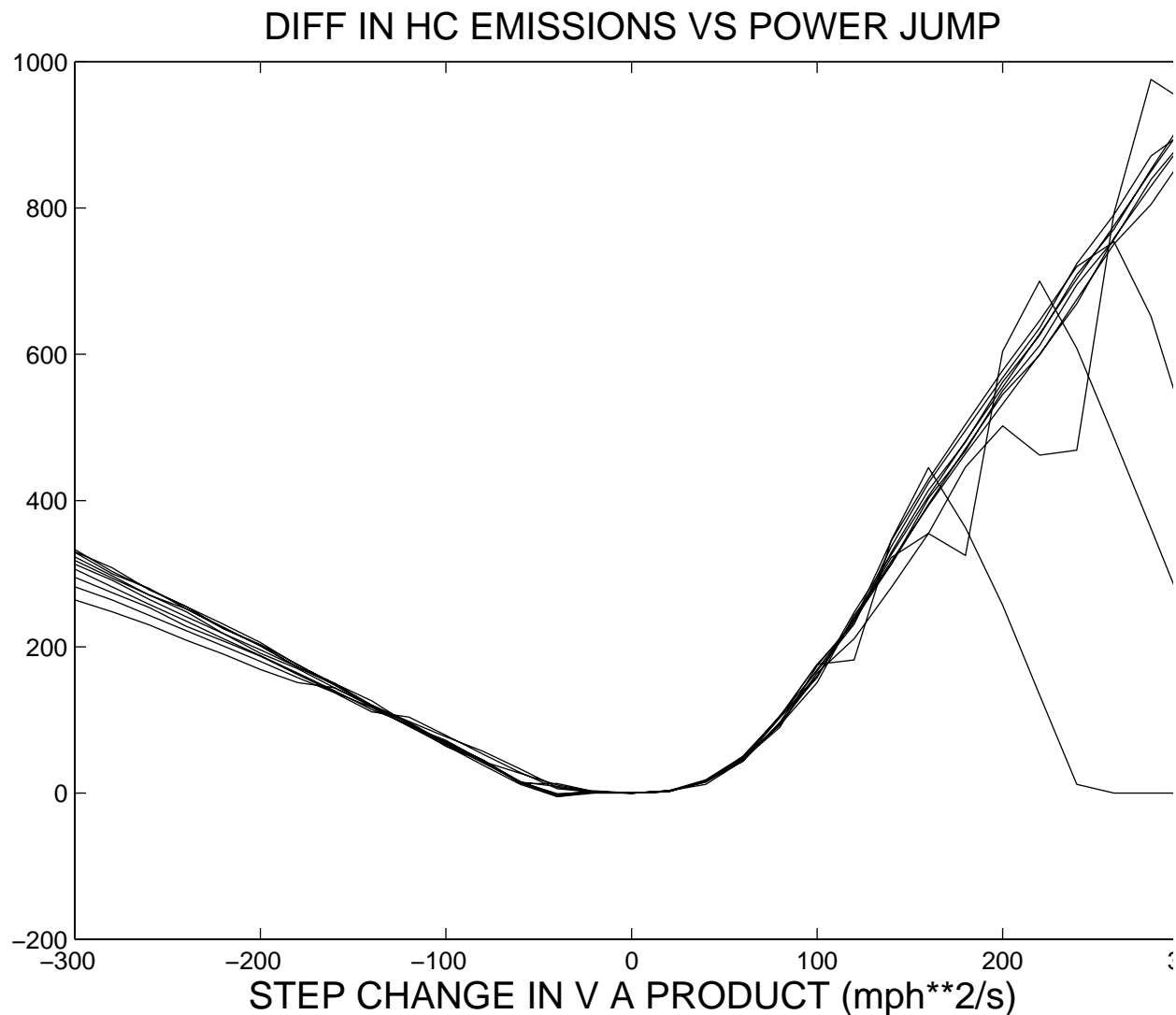
Figure 3. CO emissions as a function of velocity-acceleration product for the Riverside fleet.



For NO_x missions and hydrocarbons, there are important transient effects. Figure 4 displays the difference in hydrocarbon emissions as a function of the difference in V A product between the current time and the preceding second. These results are from a beta-version of CMEM and might be expected to change in the final version. The downsloping lines on the right-side of the plot are an artifice of the way the difference array was constructed. Emissions at constant power were subtracted from emissions associated with a jump in power. However, at low speeds and high power, it is not possible to have constant power for multiple seconds without having negative speeds.

Accordingly the “constant power” calculations are made with small positive initial speeds and the the emissions are not at exactly constant power. In fact for low final speeds and high power, the “constant power” arrays are the same as the step increase in power arrays and their differences are nil.

Figure 4. The difference in hydrocarbon emissions between those with a jump in power and those at constant power for the Riverside fleet.



Fleet status

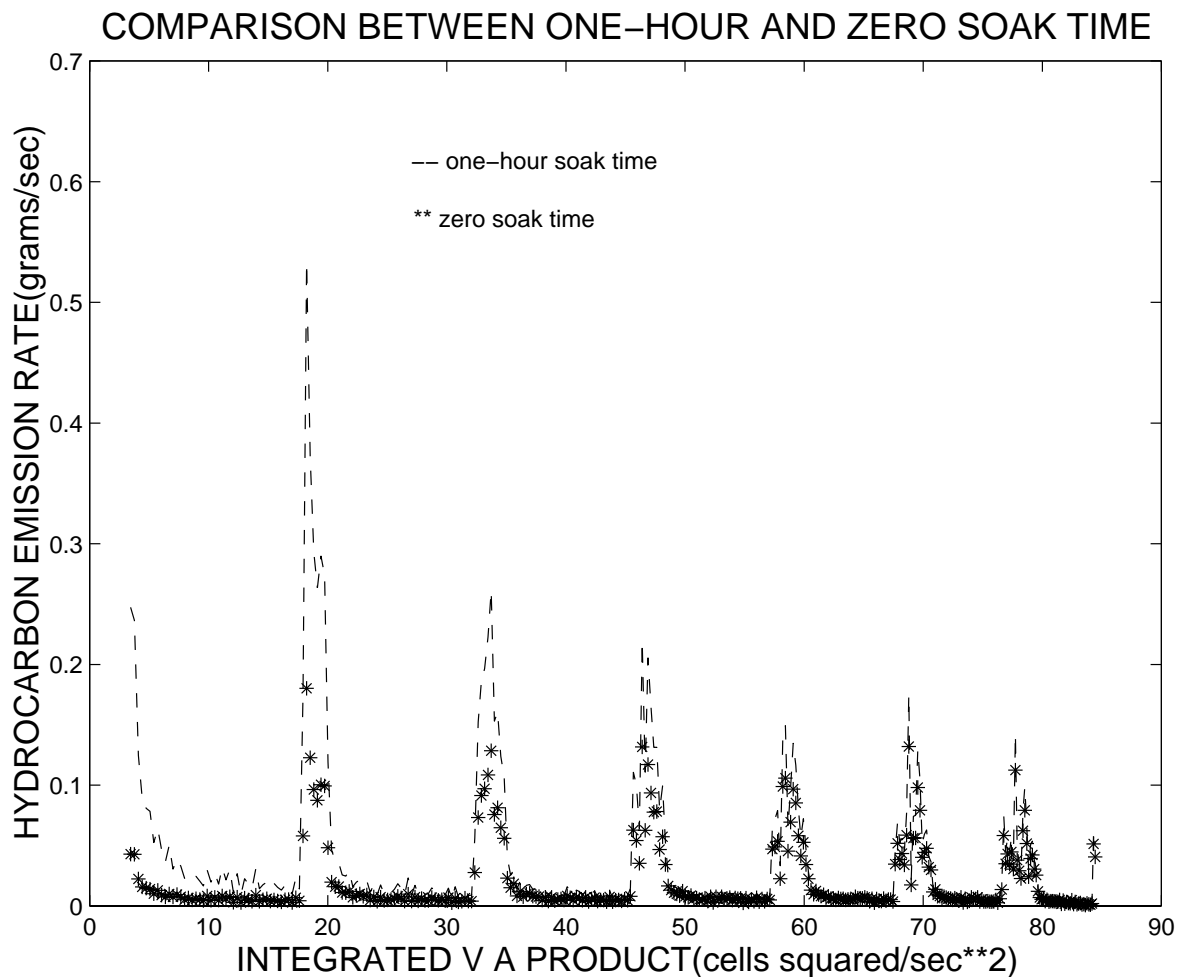
Fleet status is developed from the pattern of usage of the vehicles traversing a given link. The micro-simulation keeps track of when and where the vehicles have been operating. Cold engines burn fuel-rich until the engine has burned enough fuel to bring the engine temperature up to normal. Similarly, the catalyst efficiency is reduced until enough fuel has been burned to bring the catalyst up to normal operating ranges. Within a given vehicle category, the principal determinant of fuel consumption is power demanded.

We represent the distribution of vehicles in various stages of warm-up by grouping the vehicles entering a link into groups based on their integrated product of speed and acceleration since the last start of the engine and on the soak-time between the current operation and end of the last trip. In this version of the code there is only a single soak-time and it was based on a 1 hour time between starts. Shorter soak-times down to 10 minutes would reduce the highest ratios of cold to warm emissions by about 10% for hydrocarbons. For NO_x shorter soak-times have a larger effect, but the difference between cold and warm emissions is much less. For warm-up there are seven groupings based on velocity-acceleration product and there is an additional grouping for engines that have been fully warmed-up for a total of 8 groups. The integrated velocity-acceleration product is in units of cells-squared per second squared; a cell is 7.5 meters.

For each group we assign a multiplier for each parameter, hydrocarbons, carbon-monoxide, nitrogen-oxides, and fuel consumption. The multiplier represents the ratio of emissions for vehicles beginning a link in the group to the emissions of a vehicle with the same driving pattern with fully-warmed up engine and catalyst.

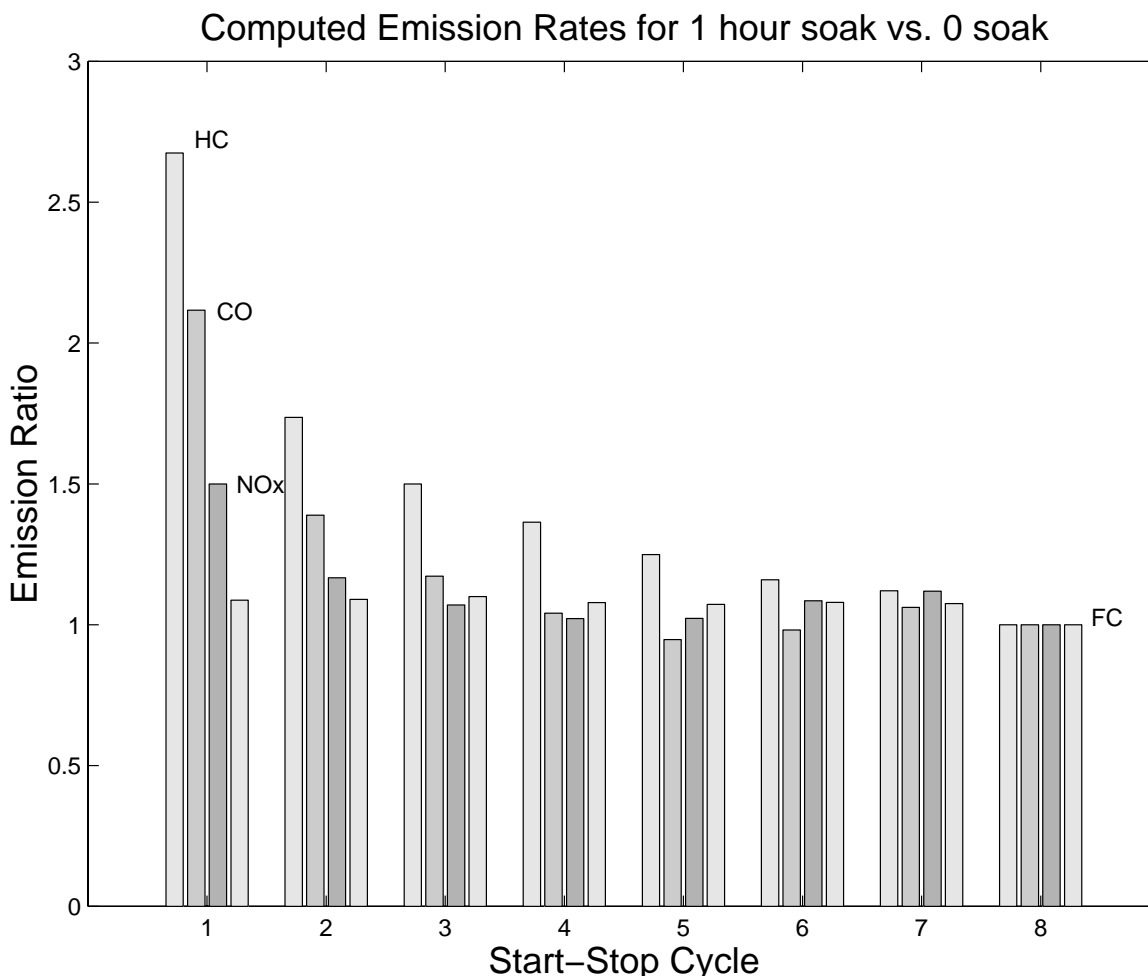
The groupings and values were obtained by taking several actual trajectories where vehicles accelerated from a near stop (less than 5 mph) at a signal and achieved typical speeds on an arterial. The original trajectories were approximately 30 seconds long and covered about one-quarter mile. The ends of these trajectories were replaced with a short-deceleration to the initial speeds and then the trajectories were repeated. In this way several trajectories with ten cycles of accelerating from a near stop and achieving speeds and decelerating were obtained. The stops were chosen to be approximately one-quarter mile apart. These trajectories were analyzed with the Comprehensive Modal Emission Model^{1,2} (CMEM) to obtain emissions for a soak-time 60 minutes. Figure 5 shows the hydrocarbon emissions for cold-engine relative to a fully-warmed up engine and catalyst.

Figure 5. Comparison between hydrocarbon emissions with and without a one-hour soak-time.



These results were used to construct ratios for each cycle by integrating the emissions curves from the start of one peak to the beginning of the next peak. For example by integrating from zero to 15, the cold-engine has about 3 times the hydrocarbon emissions of the warm-engine. The ratios are lower for the other pollutants and the all approach one after several stop-start cycles. Figure 6 reports the calculated ratios for various pollutants.

Figure 6. Emission ratios for 1 hour soak time versus 0 soak time for the Riverside fleet.



Estimation of aggregate dynamics

One of the major challenges of appropriately modeling emissions is to account for the effects of different power-demands by different drivers. With light-duty vehicles, there are a wide range of accelerations available to the driver. The driver that favors harder accelerations may put the vehicle into an “enrichment” mode. During enrichment conditions, the vehicle’s fuel controls switch to a fuel-rich situation that produces high emissions from the engine, and, since the catalyst is starved for oxygen it does not reduce the emissions significantly. This fuel-control logic protects the catalyst from getting too hot, but it enormously increases the emissions of the vehicle.

There are two options to deal with this challenge: (1) construct a fast, accurate microsimulation that describes traffic and power demands in great detail, or (2) supplement a fast microsimulation that describes traffic properly with empirical information on power demands. One of the major difficulties with option 1 is finding adequate information describing the range of driving behavior in specific circumstances. There is much more information on traffic than there is on individual driving speeds and accelerations. For this reason we have chosen option 2. We have developed a microsimulation that describes traffic accurately and efficiently. From the microsimulation we know the context in which driving occurs, and we have developed a system, the LDV Aggregate

Dynamics module, to put empirical information into the context.

The apportionment of the number of vehicles into these power/speed bins is based on relationships developed from actual measurements of vehicle behavior under a variety of conditions. First, during EPA's three city studies⁸ many vehicles were fitted with a data-logger that recorded times and speeds throughout the vehicle's travels for a significant period. This data was examined to determine what the frequency distribution of accelerations is for a given speed. More specifically we looked for the cumulative frequency of positive accelerations. Second, it is evident that for higher power levels, the frequency of a given power level falls off exponentially with power. In the case of decelerations, the frequency falls off exponentially with the velocity-deceleration product.

These relationships form one of the empirical underpinnings of our approach. We consider all accelerations in one of three groups: (1) high power, (2) insignificant accelerations, and (3) hard braking. High-power events are defined by $V A$ products greater than 50 mph squared per second. This threshold approximates the 10% point on the cumulative distribution. We estimate the number of vehicles undergoing a high-power acceleration and then choose 15 different power levels to represent different levels of aggressiveness. The power levels are chosen from the cumulative frequency distribution with equal spacings in power and covering the range from a cumulative frequency of 0.1 to a cumulative frequency of 0.0045. The total population of vehicles undergoing high-power driving from a given speed is then distributed over the 15 power (or equivalently $V A$ products) levels in accordance with the cumulative frequency distribution. These data are used to estimate the relative proportions of vehicles having different power levels within the group of vehicles that are engaging in high-power driving.

There are two circumstances in which the basic frequency-power curve is significantly different from normal: (1) freeway on-ramp driving and (2) driving at the end of signalized links. In freeway on-ramp driving, the frequency falls off much slower with power. In this case we use 90 mph squared per second as the definition of a high-power demand and -90 mph squared per second as the definition of a low-power demand. For the ends of signalized links, the curve for frequency versus the deceleration-speed product falls off much slower with negative power than it does for other circumstances.

In the module the first step is to estimate the population of vehicles in each 4 mile per hour speed bin from the populations in the 7.5 meter per second speed cells for each link segment as described previously⁷. We also use them to calculate the standard deviation of the speed in each segment along the link and estimate the average speed, average square of the speed, or the average cube of the speed in each segment. By looking at the changes in the average cube of the speed we can estimate the average power in the segment. We expect that the average power influences the probability of a high-power driving. We also expect that the probability of high-power driving is influenced by the standard deviation of speeds, because a large standard deviation of speeds implies that many vehicles are below their desired speeds and will use available opportunities to

accelerate to higher speeds. We define the parameter sp as:

$$sp = \frac{\text{gradient} - \text{of} - \text{third} - \text{moment}}{\text{zeroth} - \text{moment} \times \Delta^2}$$

for the case where the average speed is increasing and assume that the probability of high-power driving is proportional to sp . Otherwise, we assume that the probability of high-power driving is proportional to the square of the average speed times the difference between the standard deviation of speed for the link in question and that of an uncongested freeway link.

The calibration constants were determined from a power-balance, for each third of the vehicles (slowest, middle, and fastest), for high-power and low-power. Data from an uncongested freeway, a moderately congested freeway and a uncongested arterial were used in the calibration.

The powers, refer to the continuous trajectories and are calculated on a per trajectory basis. In our formulation, a single trajectory produces a flux of one-cell per second or 16.7 mph. Consequently the power for a given segment is given by the flux for that segment divided by 16.7 mph. The power, Pow , of vehicles in the high-power mode is:

$$\frac{flux}{16.7} Pow_h = p_h d \frac{(1 + e_o \alpha)}{\alpha}$$

With α as the exponent in cumulative distribution for power, e_o is the threshold for high-power driving, and d is the density of vehicles in the segment and the third of the vehicles under consideration. With Pow_h provided by the regression relations, we can solve for p_h . We can also calculate the total power for each third of the vehicle flux as:

$$Pow_{tot} = \frac{1}{2} sp d \Delta^2$$

The average power of the intermediate driving is then estimated as:

$$\overline{Pow_m} = \frac{Pow_{tot} - Pow_h - Pow_l}{d (1 - p_h - p_l)}$$

The code also accounts for vehicles that do not reach the end of link. It is assumed that these vehicles fall into the slowest third of the vehicles and sufficient flux among the slowest third of the vehicles in the segment upstream of the segment under concern is added to the downstream seg-

ment before the gradient is calculated. This procedure requires that the cutoff points between the various thirds of the flux be recalculated for the downstream segment. The underlying assumption for this procedure is that the flux should be approximately constant if all vehicles complete the link.

We used a similar procedure to the one described above to obtain the calibration constants for freeway on-ramps. We used the Cal Poly data¹⁰ to estimate trajectories for two of the on-ramps that spanned a variety of conditions. In a similar fashion, we reorganized our arterial trajectories so that all the vehicles approached a signalized-intersection at the same spatial position. We used the fast arterial trajectories to obtain the calibration constants for decelerations at the end of a link. We also tested the formulation on the other arterials and on-ramps.

We have tested this system for three levels of congestion on arterials and 7 levels of congestion on freeways⁹ in addition to a dataset drawn for the least congested arterial set, but using only the vehicles with starting speeds less than five miles per hour.

Treatment of transients in driving power

An important challenge is the representation of transient emissions associated with step changes in power. Our approach is to compute emission arrays at constant power (in fact these emissions are at constant power only if the constant power trajectories can be obtained with feasible velocities over the whole trajectory). In addition we compute arrays that give the difference in emissions between constant power trajectories and those with the same speed and power, but with a step change in power over the previous second. We then estimate the change in power between the second of interest and the preceding second. The emissions are obtained by multiplying the fractional power change times the emission difference for the given speed and power and adding the result to the emissions at constant power. We estimate the change in power as:

$$Pow_i - Pow_{i-1} = Pow_i \times \left(V_x \times \frac{(p_x - p_{x-1})}{\Delta} \right) - Pow_i \times \frac{V_x - V_{x-1}}{V_x}$$

This expression is developed from the relation between the power (Pow) and the probability of a high power event (P) while the subscript i refers to time and the subscript x refers to position. We tested this formulation against one in which the fractional power differences were taken directly from measured trajectories.

In order to construct the test, we constructed a composite vehicle using the fleet distribution representative of the Riverside, California region. With the composite-vehicle emission arrays, we calculated emissions for each second of each vehicle's travel and assigned those emissions to the 7.5 meter cell that the vehicle was in at the end of the second. For each trajectory in the original dataset we calculated 4000 trajectories beginning with random offsets within the first second of travel and the first 7.5 meters of travel. We accumulated these emissions by cell and normalized the results to represent the emissions from a single typical trajectory. We report these emissions as the "trajectory-implied" emissions.

For the estimated emissions we aggregated the vehicles in the same dataset used to obtain the "tra-

jectory-implied” emissions into 30 meter segments and 7.5 meter per second speed bins. We then fit the resulting distribution with continuous line segments in velocity and calculate the probabilities of high-power events and distribute those V A products over the power bins using the exponents from the cumulative distributions. With the speed bin and power bin populations known, we estimated the emissions for each 30 meter segment

RESULTS

Figure 7 reports the comparison between estimated and trajectory-implied results for a fast arterial leaving a signalized intersection. The fast arterial was used in the calibration of the model of the constants that effect the power balance, but the estimated fractional power changes were not calibrated. The figure illustrates the difference between the behavior of NOx and hydrocarbons which are more sensitive to changes in power that are expected at the start of links.

Figure 7. Comparison between TRANSIMS-style aggregate emissions and emissions based on second by second speeds and accelerations for a fast arterial leaving a signal.

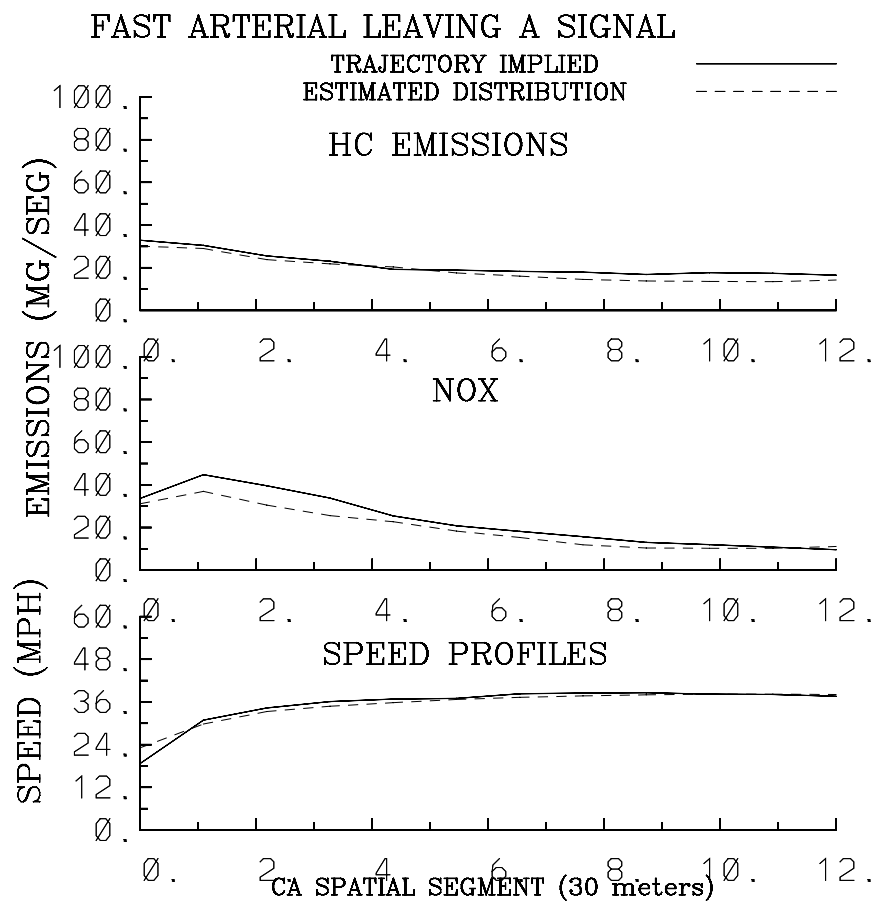


Figure 8 reports the comparison between estimated and trajectory implied emissions for a slow arterial. The slow arterial was not used in the calibration of the power-balance constants.

Figure 8. Comparison between TRANSIMS-style aggregate emissions and emissions based on second by second speeds and accelerations for a slow arterial leaving a signal.

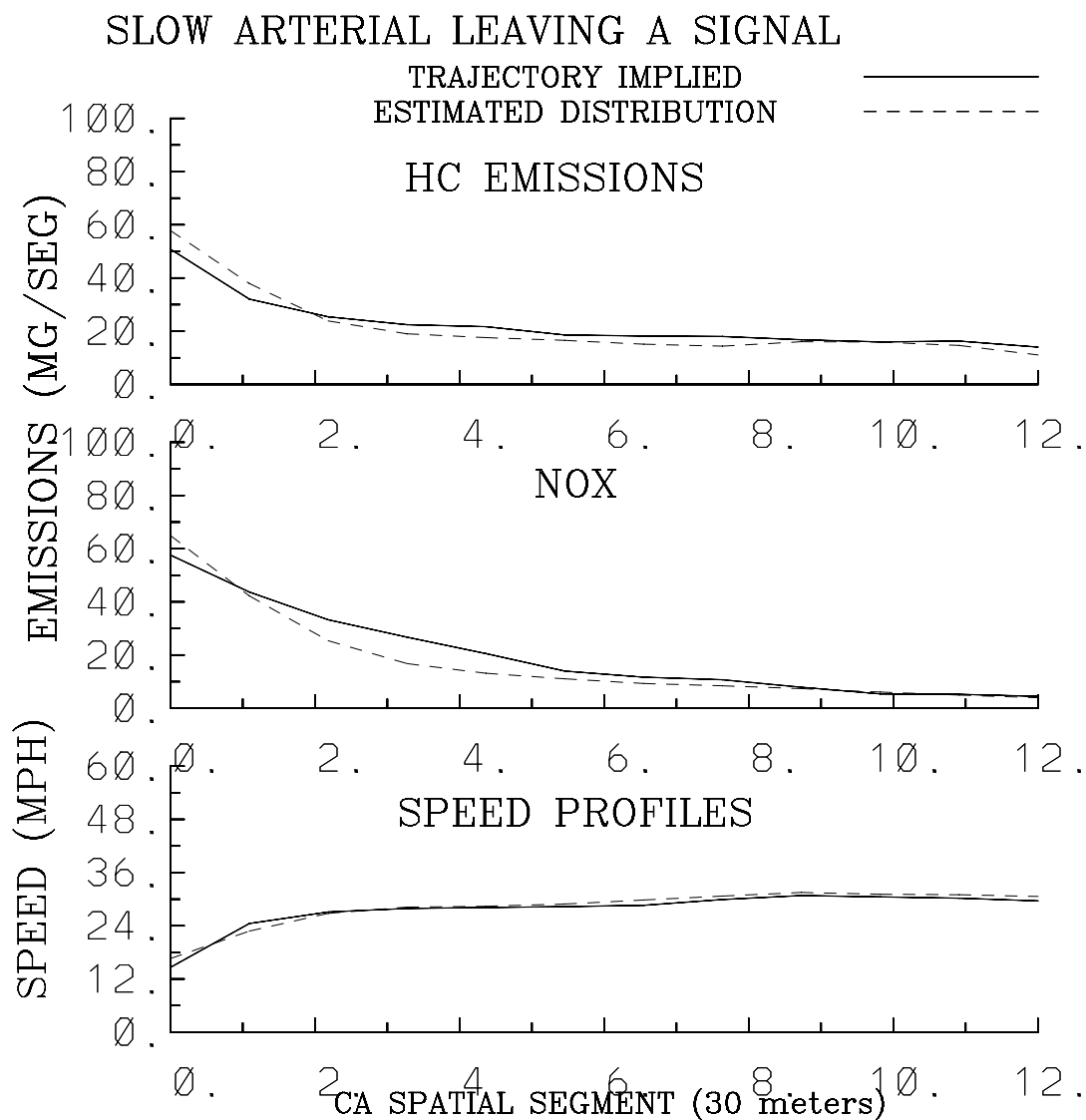
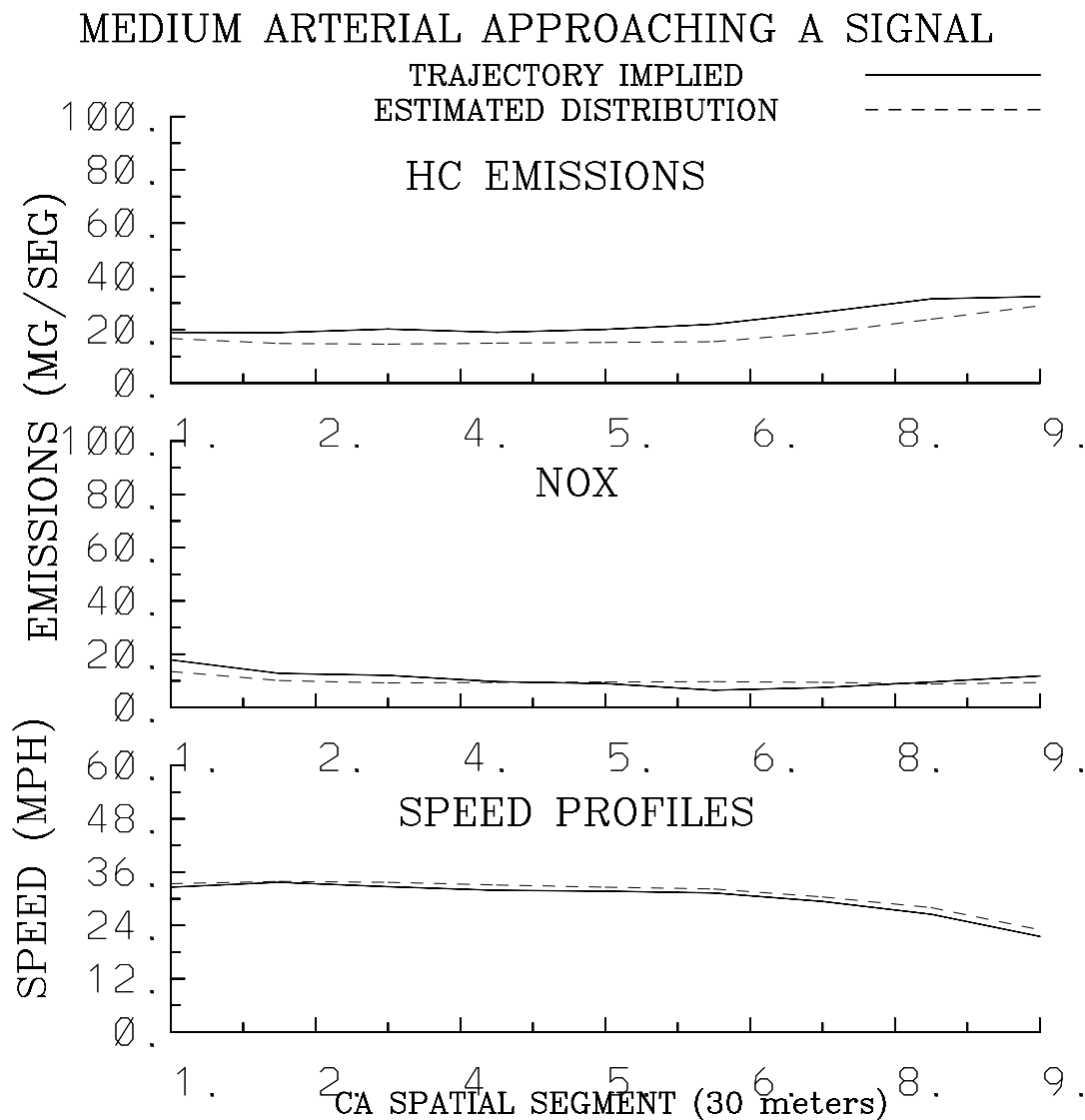


Figure 9 reports a comparison for the medium arterial approaching a signalized intersection. We can note the slight increase of hydrocarbon emissions as vehicles slow-down. The medium arterial was also not used in the calibration.

Figure 9. Comparison between TRANSIMS-style aggregate emissions and emissions based on second by second speeds and accelerations for a medium arterial approaching a signal.



In addition to work with freeways and arterials we have estimated emissions from vehicles on freeway on-ramps. The data set we used provided velocity and acceleration joint frequency distributions for several on-ramps. We made the comparison by constructing approximate trajectories. The first step in the construction of the trajectories was to estimate the distribution of speeds at the start of the ramp. We did this by estimating an array that converted the starting speeds into the speed distribution of speeds over the entire V by A distribution on the ramps that was obtained by summing the joint distribution over the accelerations. We then inverted the conversion array and multiplied it by the overall speed distribution to obtain an estimate of the starting speeds. This approach is very approximate, because not all vehicles had the same length trajectories as was assumed in the creation of the conversion array. In addition the constructed trajectories were based on one-half second time steps, while the estimated model used one-second time steps. Table

1 provides link-based comparisons for the arterials and on-ramps. On-ramps are of particular interest because the emissions are much higher on a per vehicle basis than they are on arterials or freeways.

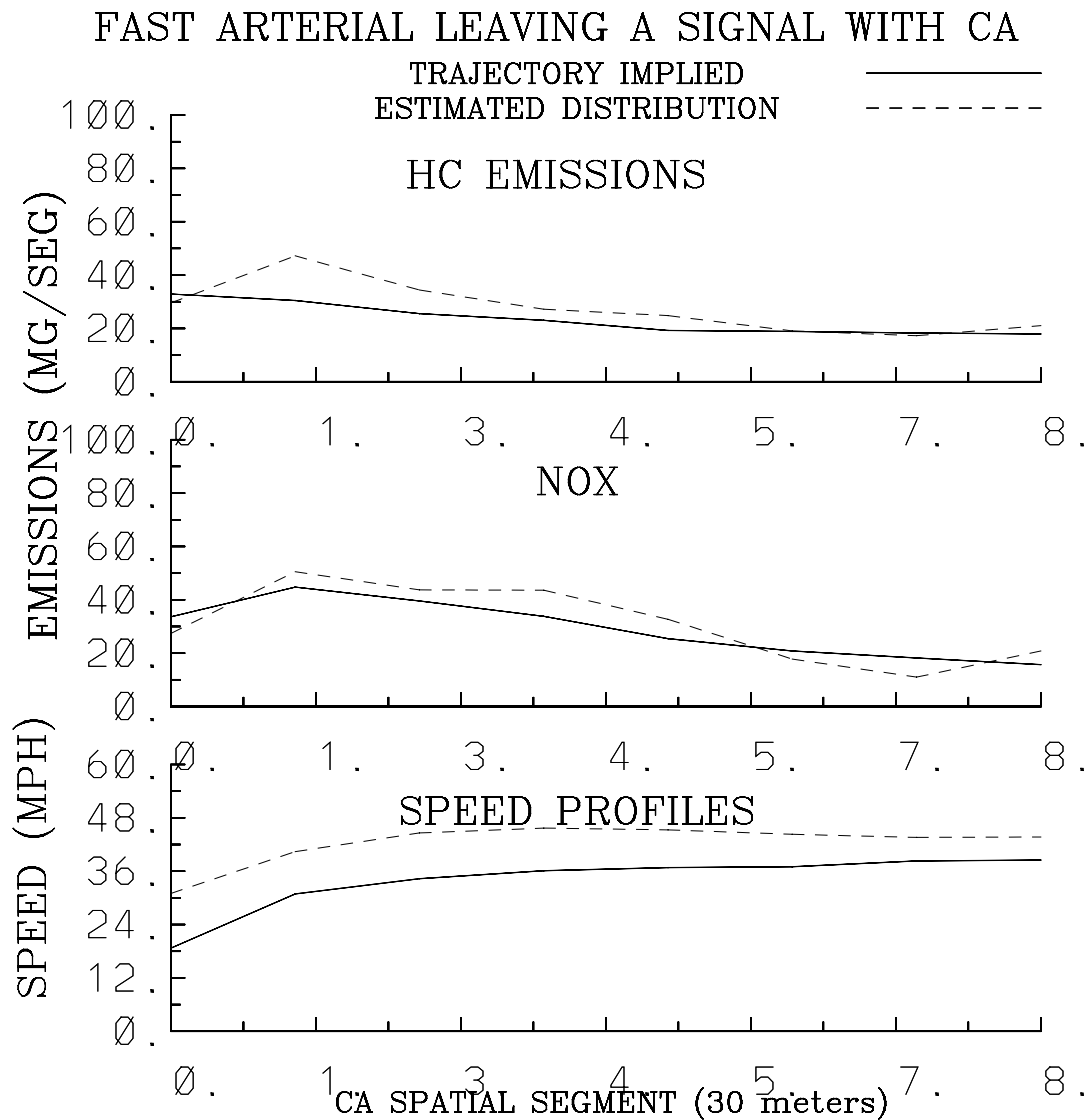
Table 1. Comparison between Estimated and Trajectory-implied Emissions.

Data set	speed (mph)	est. speed (mph)	NO _x (mg)	est. NO _x (mg)	HC (mg)	est. HC (mg)	CO (gm)	est. CO (gm)
slowest arterial slowing	25.1	25.5	107	136	182	194	2.1	3.8
medium arterial slowing	29.8	30.9	79	76	191	147	1.6	1.8
medium arterial accelerating	30.8	31.4	267	231	281	251	5.8	5.7
slow arterial accelerating	27.5	28.0	241	214	270	260	5.2	4.6
Sherman-way on-ramp	37.3	38.6	488	429	516	458	17.5	16.3
Santa-Monica -free on-ramp	32.5	33.1	286	190	315	226	8.0	6.9
La Tijera on-ramp	23.3	24.5	120	76	117	109	2.5	2.3
Las Virgenes on-ramp	22.7	24.1	189	142	226	247	6.4	5.0
Hollywood Blvd. on-ramp forced	24.5	25.2	199	134	234	176	5.3	3.1
Hollywood Blvd. on-ramp free	28.7	30.9	121	143	244	132	4.6	6.2

These results show that vehicle populations that are lumped into 30 meter segments and 7.5 meter- per-second speed bins can be used to produce emissions that are similar to those obtained from individual second-by-second trajectories.

We have also done a preliminary comparison between CA output for uncongested traffic leaving a signal on an arterial with the emissions from the fast arterial. In this instance, the coefficients have not been calibrated. Figure 10 reports the results.

Figure 10. Comparison between TRANSIMS emissions and emissions based on second by second speeds and accelerations for an uncongested arterial leaving a signal. In this case the fast arterial data was taken as representative of an uncongested arterial.



CONCLUSIONS AND FUTURE WORK

We have developed a system for converting aggregate spatial and velocity groups into distributions of speeds and accelerations appropriate for emission calculations using the TRANSIMS framework. Critical parameters for emissions calculations are: (1) the number of vehicles entering the link, (2) the gradient in speeds along the link, and (3) the standard deviation of speeds in each portion of the link. The testing of the system also provides insight into vehicle emission behavior. On a per trajectory basis the NO_x emissions per unit distance are relatively insensitive to average speed, but they increase significantly with the gradient of speed and are highest as vehicles leave intersections. For hydrocarbons the emissions are high as vehicles leave or approach intersections,

but they are also high on very congested links. All emissions are very high on freeway on-ramps.

We need to calibrate and test the module with CA data from the TRANSIMS microsimulation in situations where both measured trajectories and measured densities are available.

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